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D I P H A S I C   A R M O R

1. Glass - Doron

by

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Summary

1. For an armor to be effective, the kinetic energy of the moving missile must be absorbed and dissipated. Two main properties combine to make up a good armor: "toughness" and "drag" resistance.

2. Two specific features of the projectile are involved: the effective area of impact on the armor, and the profile and surface area for drag resistance. Increase in the area of impact and in the dragging area effects an increase in ballistic performance of a given armor material. This increase may be accomplished by mushrooming, yawing and breaking up the projectile. Further increase in performance may be obtained by a "mass" effect or "free object" effect which acts to lower the velocity with which the armor is struck. Deflection or ricochet of the missile is also to be considered.

3. A new combination of materials has been developed which has potential value as armor. This armor is made up of glass bonded to Doron and is the result of a happy combination of theory and experiment. In use the glass is placed on the front surface towards the point of expected impact. Glass-faced Doron type laminates have been made for experimental use by the Paint Division, Pittsburgh Plate Glass Company.

4. Testing of single samples of armor was accomplished using a Ballistic Box which enabled direct comparison between the missile resistance of the unknown sample and a given standard material. Doron, kindly furnished by the Office of the Quartermaster General, Army Service Forces, was used as the standard. The test guns were the U.S. Carbine with 110 grain bullet at 1900 feet per second, and the U.S. Springfield with M2 (ball) 150 grain bullet at 2700 feet per second.

5. Three kinds of glass-faced Doron were tested: Window glass, plate glass, and Herculite glass. Samples of Hadfield manganese steel bonded to Doron were also tested.

6. The average per cent rating of Glass-Doron combinations against the carbine compared to Doron was 64.2, and the average critical weight of Glass-Doron to just resist the carbine was 3.70 pounds per square foot compared to 5.76 pounds per square foot for Doron alone.

7. The addition of a four-ply flexible Doron cushion between the glass and the Doron did not measurably increase performance.

8. The average per cent rating of Glass-Doron against the Springfield M2 (ball) compared to Doron was 69.7 at a critical weight of

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9.37 pounds per square foot compared to 13.44 pounds per square foot for Doron alone.

9. Hadfield steel bonded to Doron was not superior to Doron alone.

10. The ratio of the weight of armor material to just stop the carbine to the weight of armor to just stop the M2 (ball) was very close to the ratio of the kinetic energies of the respective bullets.

11. Sufficient data was not obtained to evaluate the influence of the type of glass used as a facing for Doron. The three types showed little difference under the method of testing used.

12. Suggestions are made for future research and for determining the optimum ratio of glass to Doron for maximum ballistic efficiency.

1. <u>Principles Behind Glass-Doron Armor</u>:- Theory alone indicates that for any armor to stop any given projectile the kinetic energy of the moving missile must be absorbed. In general, the armor should have the physical property of "toughness" which represents the ability of the material to deform without rupture, to "detrude under impact", and hence, the ability of the material to have work done upon it by the moving missile. "Toughness" is measured by the area under an impact stress-deformation curve taken to the point of rupture. The relation between this measure of "toughness" and the static stress-deformation curve needs more careful evaluation. This property of "toughness" is most generally manifest when the projectile is <u>large</u> in comparison with the thickness of the armor, and hence, when the projectile does not enter the material itself but rather "presses on the surface" of the armor.

In addition to the above, certain armor materials have the ability to "soak up" kinetic energy by virtue of the inherent resistance of the material to penetration after the missile has embedded itself in the substance. This property is somewhat analogous to viscosity or drag in a fluid or gas and its effect increases with increase in the surface area of the projectile. This property, which I have called "drag" to distinguish it from "toughness" is of particular importance in the case of <u>small</u> projectiles such as fragments from grenade and shells in which the surface area is large compared to the mass.

The preceding paragraphs have argued that in order to stop a moving projectile, the kinetic energy must be absorbed. The question arises as to what can be done to further the absorptive powers of a given armor material. Based on the property of "toughness" the energy absorbed will increase as the effective area of impact (or the effective caliber) of the projectile is increased. Thus, the loading per unit area should be made as small as possible.

Obviously, one can drive a nail through a board, but it is difficult to drive the head of the hammer through the board. Based on the property of "drag" the energy absorbed will increase as the surface area of the missile is increased. Therefore, to accomplish an increase in the area of impact we must spread the blow from the projectile, and to accomplish an increase in the dragging area we must break up the projectile. Specifically, we may increase the energy absorbed by a given armor material by

a. increase in the area of impact, by

1. mushrooming the projectile,
2. yawing the projectile,
3. breaking up the projectile into smaller fragments, and

b. increase in the surface area by

1. breaking up the projectile into smaller fragments.

Two other possible factors, not directly related to the preceding may enter the picture in the design of armor:

a. deflection or ricochet of the projectile by

1. hard surface, and

b. a "mass" effect or "free object" effect in which secondary missiles are formed and the armor is ultimately struck at reduced velocities. This may be of particular value for armor which has impact ductility at low velocities but not at high velocities.

Previous memoranda to Rear Admiral H. W. Smith (MC), USN, of 30 June 1945, 16 March 1945, 8 February 1945, 3 October 1944, 22 September 1944, and 5 August 1944, have given the results of experiments designed to yaw, break up and deflect bullets from 0.30 caliber rifles, using "grills" of various shapes on the surface of Doron. These grills were composed of hardened steel rods, steel U-channels, steel pyramids (to cut and rip), and glass spheres (to increase area of impact, yaw, break up, deflect, and produce secondary missiles). In general, the conclusions from these experiments were to corroborate the principles outlined above, and to suggest the use of the hardest substance obtainable for bonding to the surface of Doron in order to mushroom the bullet, yaw it, deflect it, and break it up. Accordingly, samples of glass bonded to Doron were procured for testing.

2. The Test Material:- Through the kindness of Dr. E. H. Haus, Special Technical Representative, Paint Division, and Dr. W. H. Lycan, Director, Paint Division Research, of the Pittsburgh Plate Glass Company, a number of samples of window glass, plate glass and Herculite glass were bonded to Doron in 15 and 21 ply and sent to me for testing. Some of the samples were made by cementing 15 ply and 21 ply Doron (Selectron 5003 binder) to the various types of glass using modified Selectron 5003 resin. Other samples were made by laminating the glass

cloth and cementing to the glass simultaneously, i.e., a one-step process in the manufacture of glass-faced Doron type laminates. Still other samples were made using a cushion of Selectron 5009 flexible type Doron between the glass and the Selectron 5003 plastic armor (Doron). In addition, samples of Hadfield manganese steel bonded to Doron were included in the series. Samples of bullet-resistant glass were also obtained. A complete list of code numbers and method of manufacture as given me by Dr. Lycan is reproduced in Table 1.

3. Method of Testing:- After the original idea of using a facing of glass bonded to Doron was proposed and the samples received from the Pittsburgh Plate Glass Company, the problem arose as to how to test single samples of an unknown armor material. Obviously, one would wish to evaluate the unknown samples in terms of some standard, such as 24 ST aluminum alloy. Other ballistic research groups do just this using a number of samples and simulated fragments at measured velocities, firing until a "limiting velocity", critical for penetration, is found. Then the weight of the unknown sample is compared, on a percentage basis, with the weight of a standard (24 ST aluminum alloy) which is also just critical for this velocity and weight fragment.

This procedure was beyond the scope of the facilities at the Bureau of Medicine and Surgery, and further requires a number of the same type of samples. Accordingly, a simple method of testing was devised which required but one unknown sample and could be done without laboratory facilities. A thorough description of the test device, method of testing and procedure to evaluate the armor was given in a memorandum to Rear Admiral H. W. Smith (15 March 1945).

Briefly, the test device consists of a Ballistic Box or Ballistic comparator composed of a series of 1/2 inch thick slabs of aluminum, 8 by 8 inches square, with a hole 4-1/2 inches in diameter in the center. The slabs are stacked with plates of the standard material (to which the unknown is to be referred on a percentage basis) between each slab, the whole then being held together by means of four long threaded bolts at each corner. The test sample of unknown armor material is placed between the first and second slab. The gaps between the slabs are denoted as zones.

The Ballistic Box reverses the usual laboratory procedure of firing a projectile at various velocities against a number of samples, but uses instead a constant gun, having a known bullet weight and velocity, fired against a single unknown sample which is backed up by sheets of a standard material to which the unknown is to be

TABLE 1

CODE	Doron (ECC-165)	Pressure Used	Glass	Remarks
160 - 40	15-ply	Bookbinder's clamps	3/16" plate	Straight cementing with Hadfield Selectron 5003
160 - 40 A	"	"	window	"
160 - 40 B	"	"	1/4" Herculite	"
160 - 40 D	21-ply	"	window	"
160 - 40 E	"	"	1/4" Herculite	"
160 - 40 G	"	250 #/in²Carver Press	3/16" plate	1-step process
160 - 40 H	"	"	window	"
160 - 40 T	15-ply	Bookbinder's clamps	window	4-ply laminate 4ECC-165 (crosswise), Selectron 5009.
160 - 40 L	21-ply	"	window	"
160 - 40 M	"	"	1/4" Herculite	"
160 - 41 A	"	---	3/16" plate	4-ply 5013 cushion
160 - 41 B	"	---	window	"

			Hadfield Steel	
160 - 78 B	15-ply		.045 in.	
160 - 78 F	21-ply		.045 in.	
160 - 78 E	15-ply		.090 in.	
160 - 78 I	21-ply		.090 in.	

subsequently compared. Initially, the constant gun is fired into the Ballistic Box using only the standard material between the slabs. Let the weight of the standard necessary to just stop the missile, i.e., the critical weight, be called A. The gun is then fired through the unknown sample backed up with the standard, all in the Ballistic Box. Let S denote the weight of the standard material which is just required to stop the missile after it has penetrated the unknown. The value of S is a measure of the remaining energy after the unknown armor sample is penetrated. Let U denote the weight of the unknown armor sample penetrated, and U_e the weight of standard material equivalent to U in bullet resistance for this test. Then

$$U_e + S = A$$

and

$$U_e = A - S$$

The per cent rating of the unknown armor plate is then given by

$$P = \frac{U}{U_e} 100$$

or

$$P = \frac{U}{A-S} 100.$$

The critical weight of unknown material to just resist the missile from the constant gun is then given by

$$U_c = \frac{PA}{100}$$

or

$$U_c = \left(\frac{U}{A-S}\right) A.$$

Throughout this work all weights are in pounds per square foot.

It was originally desired to use 24 ST aluminum alloy or Hadfield manganese steel as the standard, but due to inability to procure sufficient quantities of these materials, and further, these materials did not lend themselves well to the Ballistic Box as they are too easily penetrated by 0.30 caliber rifle fire, it was decided to use Doron itself as the standard. Accordingly, request was made to Army Service Forces, Office of the Quartermaster General, and through the kindness of this office sufficient Doron cut to 6 by 6 inches square to fit the Ballistic Box was delivered to the Bureau of Medicine and Surgery. Table 2 lists the code numbers and description of the Doron used as standard.

4. Results of Testing Glass-Doron in the Ballistic Box:- The weights of the unknown samples of glass bonded to Doron were calculated by the formula

$$U' = 0.08n + 13.16t + 0.25 \#/ft^2$$

where n is the number of ply of Doron, t is the thickness of the glass in inches, and 0.25 is the average weight of the bond or the average weight of the cushion. The value of 0.25 was obtained by weighing a number of samples and taking the average difference between these weights and the weight of glass plus Doron calculated by 0.08n plus 13.16t. The value of 0.08 was taken as the average weight per square foot of one-ply Doron, and the value of 13.16 was taken as the weight per square foot of a one inch thick piece of glass. This procedure for weights was adopted because of lack of accurate information on the weights of the samples used. The thickness of the window glass was not given when the samples were submitted. This thickness was estimated to be 0.116 inches and the weight of window glass as 1.53 pounds per square foot.

For the purposes of calculations using the Ballistic Box, only the weight of glass and Doron was used for U in the equation,

$$U = 0.08n + 13.16t$$

in all cases but those in which the unknown sample was not penetrated. For these cases U was taken as

$$U = 0.08 \left(\frac{n}{2}\right) + 13.16t$$

This system of halving the last plate of material on which the missile was stopped was used throughout the work, since it was felt that this gave a closer approximation to the true critical weight. For example,

TABLE 2

R-926-2-1 through R-926-2-12 incl., 42-ply

R-1560-TT-3 through R-1560-TT-14 incl., 22-ply

R-1560-SS-3 through R-1560-SS-14 incl., 22-ply

R-810-F-1 through R-810-F-3 incl., 15-ply

R-925-C-1 through R-925-C-9 incl., 15-ply

R-1494-E-3 through R-1494-E-14 incl., 16-ply

R-1494-I-3 through R-1494-I-14 incl., 15-ply if the bullet penetrated two 16 ply plates of Doron after penetrating the unknown, and was stopped after striking the third Doron plate, the bullet trapped in the third zone, the residual weight of Doron, S, is calculated as

$$S = 0.08\ (32) + 0.08\ (8) = 3.20\ \text{lbs./ft}^2.$$

Table 3 summarizes the results and calculations using the carbine, 110 grain bullet, 1900 feet per second, zero degrees yaw and zero degrees obliquity as the constant gun. The gun was fired by hand from a range of 30 feet. Lieut. Comdr. E. L. Corey H(S), USNR, did all the firing and collaborated in the tests reported here.

Although the samples differed in (a) the kind of glass used as a facing, (b) the percentage of glass and Doron, and (c) the presence or absence of a cushion, it was decided to average the results because of the similarity and apparent consistency of the data. The average per cent rating of the Glass-Doron compared to Doron was 59.87, and the average critical weight of Glass-Doron to just resist the carbine was 3.45 pounds per square foot compared to 5.76 pounds per square foot for Doron alone. With the weight of the bond included the average critical weight of Glass-Doron was 3.70 lbs./ft^2., and gives an average per cent rating of 64.24 per cent. Early in the work it was perceived that the addition of the cushion did not measurably increase ballistic performance but merely added to the weight of the sample.

Table 4 gives the results and calculations using the Springfield rifle and 0.30 caliber M2 (ball) ammunition, 150 grain bullet, 2700 feet per second, zero degrees yaw and obliquity as the constant gun. The gun used was the Army's Sniper rifle with telescopic sights. The gun was fired at the Ballistic Box from a range of 45 feet by Lieut. Comdr. E. L. Corey.

The average per cent rating of the Glass-Doron compared to Doron was 67.86, and the average critical weight was 9.12 pounds per square foot compared to 13.44 pounds per square foot for Doron alone. With the bonding resin or cushion included the average critical weight was 9.37 lbs./ft.^{2}, giving a per cent rating of 69.72. These results are in fair agreement with those obtained from the carbine.

5. <u>Results of Testing Steel-Doron in the Ballistic Box</u>:- Table 5 summarizes the results and calculations using Hadfield manganese steel bonded to Doron. The weights of the unknown samples were calculated as follows:

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TABLE 3

	CODE	U, weight of test sample lbs./ft^2.	A, lbs./ ft^2 of Doron	S, residual Doron penetrated lbs./ft.^{2}	U_e = A-S, Doron Equivalent of U	Per cent Rating $\frac{U}{U_e}$ 100 = $\frac{U}{A-S}$100	Cl_c, critical weight for penetration, $(\frac{U}{A-S})$A, lbs./ft.^{2}.	Per cent Doron
	(Doron alone		5.76					
Carbine	(160 - 40 A	2.73	5.76	0.60	5.16	52.91	3.05	43.96
	(160 - 40 D	3.21	5.76	0.60	5.16	62.21	3.58	52.34
	(160 - 40 I	2.73	5.76	1.20	4.56	59.87	3.45	43.96
	(160 - 40	3.07	5.76	0	5.76	53.30	3.07	32.70
	(160 - 41 B	3.21	5.76	0.88	4.88	65.78	3.79	52.34
	(160 - 41 A	3.31	5.76	0	5.76	57.47	3.31	40.48
	(160 - 40 B	3.89	5.76	0	5.76	67.53	3.89	26.73
					Average	59.87	3.45	41.79
			Average with bond or cushion			64.24	3.70	

TABLE 4

	CODE	U	A	S	U_e	Per cent Rating	Cl_c	Per cent Doron
M2(Ball)	(Doron alone		13.44					
	(160 - 40 M	4.97	13.44	5.76	7.68	64.71	8.70	33.80
	(160 - 40H + 40L	6.42	13.44	4.40	9.04	71.02	9.55	52.34
	(160 - 40G + 40E	9.12	13.44	0	13.44	67.86	9.12	36.84
					Average	67.86	9.12	40.99
			Average with cushion			69.22	9.37	

TABLE 5

	CODE	U	A	S	U_e	Per cent Rating	Cl_c	Per cent Doron
Carbine	(160 - 78 B	3.00	5.76	2.64	3.12	96.15	5.54	40.00
	(160 - 78 F	3.48	5.76	2.16	3.60	96.67	5.57	48.28
	(160 - 78 E	4.80	5.76	0.88	4.88	98.36	5.67	25.00
	(160 - 78 I	5.28	5.76	0.88	4.88	108.20	6.23	31.82
					Average	99.85	5.75	36.28
				Average with bond		104.17	6.00	

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$$U' = 0.08n + 40t + 0.25$$

where n and t are number of ply for Doron and thickness of steel in inches, respectively, and 0.25 is the average weight of the bond. For the initial calculations in the table the weight of the bond was not included. For the carbine the average per cent rating was 99.85 without the bond and 104.17 with the bond. The average critical weights are 5.75 without and 6.00 with the bond. For the M2 (ball) ammunition the average per cent rating without the bond was 117.41 at an average critical weight of 15.78 pounds per square foot, and with the bond accounted for, 119.27 per cent at a critical weight of 16.03 pounds per square foot.

6. Armor to Stop the Carbine Compared to Armor to Stop the M2 (ball):- In all of this work the ratio of the weight of armor material, regardless of the type, to just stop the carbine to the weight of armor material to just stop the M2 (ball) is very close to the ratios of the kinetic energies of the respective bullets. The kinetic energy of the carbine, 110 grain bullet at 1900 feet per second is 881 foot-pounds, and the kinetic energy of the M2 (ball), 150 grain bullet at 2700 feet per second is 2426 foot-pounds. We then have the following ratios:

$$\frac{\text{Energy in carbine}}{\text{Energy in M2(ball)}} = \frac{881}{2426} = 0.363$$

$$\frac{\text{Doron for carbine}}{\text{Doron for M2(ball)}} = \frac{5.76}{13.44} = 0.429$$

$$\frac{\text{Glass-Doron for carbine}}{\text{Glass-Doron for M2(ball)}} = \frac{3.45}{9.12} = 0.378$$

$$\frac{\text{Steel-Doron for carbine}}{\text{Steel-Doron for M2(ball)}} = \frac{5.75}{15.78} = 0.364$$

It was found, using 0.045 inch sheets of Hadfield manganese steel in the Ballistic Box, that it required 9.9 pounds per square foot to just stop the carbine. The weight required for the M2 (ball) is then calculated to be 9.9/0.363 = 27.27 lbs./ft.^{2}.

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Tests of bullet-resistant glass against the M2 (ball) gave an approximate critical weight of 22 lbs./ft^2. The weight of glass alone for the carbine is then calculated to be approximately 8 lbs./ft^2.

7. Summary of Per Cent Ratings and Critical Weights of Armor to Just Stop the Carbine and the M2 (ball):- Table 6 gives the average per cent ratings of Glass-Doron, Hadfield steel-Doron, Doron alone, and Hadfield steel alone compared to Doron and to Hadfield steel. Weight of the bond has been included.

TABLE 6

		Per cent Rating	
Material	Bullet	To Doron	To Hadfield Steel
Glass-Doron	Carbine	64.2	37.4
" "	M2(ball)	69.7	34.4
Hadfield Steel-Doron	Carbine	104.2	60.6
" " "	M2(ball)	119.3	58.8
Doron	Carbine		58.2
"	M2(ball)		49.3
Hadfield Steel	Carbine	171.9	
" "	M2(ball)	202.9	

Table 7 gives the average critical weights in pounds per square foot for the various materials against the carbine and the M2 (ball). Weight of the bond has been included.

TABLE 7

Material	Carbine	M2 (ball)
Glass-Doron	3.70	9.37
Doron	5.76	13.44
Hadfield Steel-Doron	6.00	16.03
Glass	8 *	22
Hadfield Steel	9.90	27.27*

* Calculated by 9.90/0.363 = 27.27 and 22(0.363) = 8.

8. Indicated Experimental and Practical Trend of Foregoing Work:- Insufficient data are given to properly evaluate the influence of the type of glass used as a facing for Doron. Apparently the three types tested, window glass, plate glass, and Herculite glass showed very little difference under the method of testing used. The window glass and the plate glass seemed to show slight superiority over Herculite but these differences may be due to experimental error or to the varying percentages of glass and Doron in the combinations.

This raises the interesting point of determining the optimum ratio of glass to Doron for maximum ballistic efficiency. To illustrate, I have plotted what I have called a Ballistic Resistance Diagram (BRD). These diagrams give the critical weights as ordinates for various percentage combinations of the two armor materials as abscissae. Fig. 1 is a BRD for glass and Doron against the carbine, 110 grain bullet at 1900 feet per second. The smooth curve through the data has been sketched in by inspection and more complete data may alter its shape. This diagram suggests that accurate and complete data may be required to evaluate the properties of various combinations.

One can theorize generally, as follows: A given armor material has a critical weight for a given missile of D_c pounds per square foot. Another material, assumed harder than the first, has a critical weight for the same missile of G_c pounds per square foot. When the two materials are placed in apposition with the harder substance toward the point of impact, the critical weight becomes U_c which is less than D_c or G_c (whichever is the largest) for all percentage combinations of the two materials. Experimentally, BRD's should be made of various materials in combination to yield information on the effects of varying physical properties and to lead to determining minimum weights of armor for maximum ballistic performance.

BRD's should be prepared for steels of the pluramelt type as manufactured by the Allegheny-Ludlum Steel Corporation, and for face-hardened armor plate of the type as manufactured by the Diebold Safe and Lock Company to determine the optimum percentage of hard face to soft back.

Figure 2 is a BRD for glass and Doron against the M2 (ball), 150 grain bullet at 2700 feet per second, and Fig. 3 is a BRD for Hadfield steel and Doron against the carbine. The BRD's of Figs. 1, 2, and 3 are not to be presumed exact but are merely illustrative of the potentialities in this direction.

Figure 4 is a composite of Figs. 1 and 2 in which the critical weights are plotted in pounds per square foot per foot-pound of energy.

On the hypothetical side we can argue that the kinetic energy of the missile must be absorbed by the armor in order to resist the missile. Actually, some of the kinetic energy of the moving projectile goes into permanent deformation of the armor, some into permanent deformation of the missile, and the remainder into heat. Neglecting the energy to deform the missile it follows that the energy of the missile, E, may be considered equal to the energy absorbed by the weight of the first material considered alone, E_g, plus the energy absorbed by the second material considered alone, E_d, plus an additional quantity of energy due to the properties of the combination, E_{gd}.

$$E = E_g + E_d + E_{gd}.$$

On a fractional basis,

$$f = \frac{E_{gd}}{E} = 1 - \frac{G}{G_c} - \frac{D}{D_c}$$

and

$$f = 1 - \frac{aU}{G_c} - \frac{bU}{D_c}$$

where a is the percentage of substance G and b is the percentage of D in the combination U, and G_c and D_c are the critical weights of the two substances considered alone. For example, taking the average critical weight of Glass-Doron to stop the carbine, 3.45 pounds per square foot at an average percentage of Doron of 41.79, we have 2.01 pounds per square foot of glass and 1.44 pounds per square foot of Doron equivalent to 18 ply. Then

$$f = 1 - \frac{2.01}{8} - \frac{1.44}{5.76} = 0.499$$

For the M2 (ball) at $U = 9.12$, $b = 40.99$, we have

$$f = 1 \frac{5.38}{22} - \frac{3.74}{13.44} = 0.477$$

For the carbine or the M2 (ball) at the muzzle, the energy absorbed due to the combination of glass and Doron is approximately 49% of the total kinetic energy of the bullet.

Obviously, the physical properties of the two materials must be such as to make E_{gd} as large as possible. Future work should trend toward evaluating the physical properties of facings and backings which make E_{gd} large.

On the practical side we have a major disadvantage of glass-Doron combinations, namely, that of the shattering and pulverizing of the glass. In general, the glass does not splinter or produce secondary missiles, but rather, it pulverizes and powders under impact. More careful work on the bonding resin is indicated to reduce delamination of the glass when it is struck. Further, attempts should be made to coat the surface of the glass either with various resins, one ply Doron, one ply Nylon or similar material in order to reduce overall flying of glass debris when the armor is struck.

Glass-Doron armor should be thoroughly tested with 20 MM and 40 MM fragments and with the yaw-dart to evaluate the optimum ratio of glass to Doron for fragments and to evaluate the efficiency of Glass-Doron compared to other materials. BRD's could be prepared for a constant weight of sample with limit velocities as ordinates against percentage composition as abscissae. In addition, BRD's should be prepared for Glass-Doron against various projectiles at various angles of obliquity.

Apparently, the bonding resin or a cushion merely adds weight to the sample. One can surmise that the closer the Doron is to the glass the more effective the detrusion of the glass will be in spreading the impact over the surface of the Doron. The bond or cushion tends to separate the glass from the Doron allowing the glass to "give" before it has a chance to "press" against the Doron. Careful work on the bonding resin is suggested with attempts to make the bond as thin as possible.

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Fig. 1

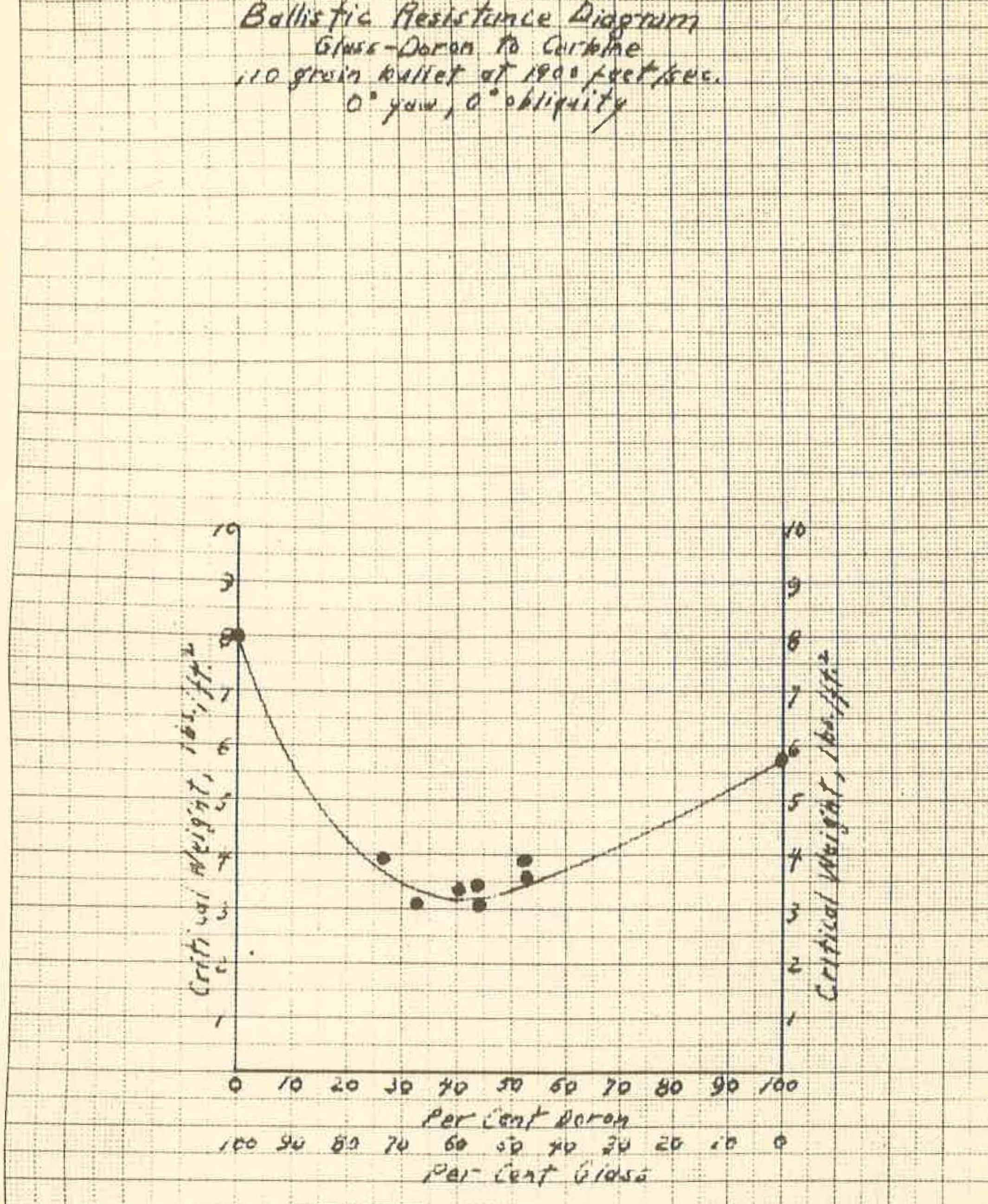

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Fig. 2

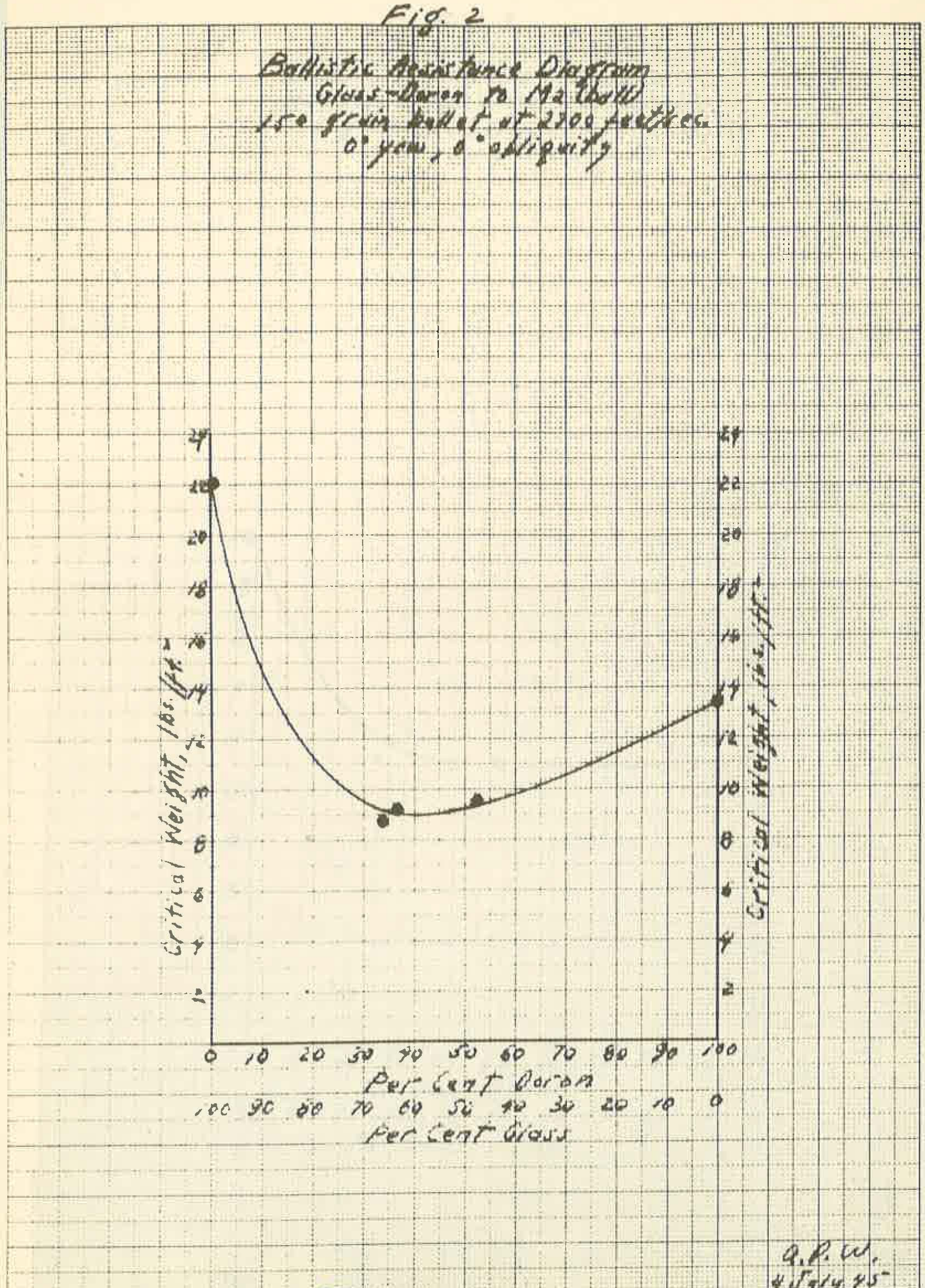

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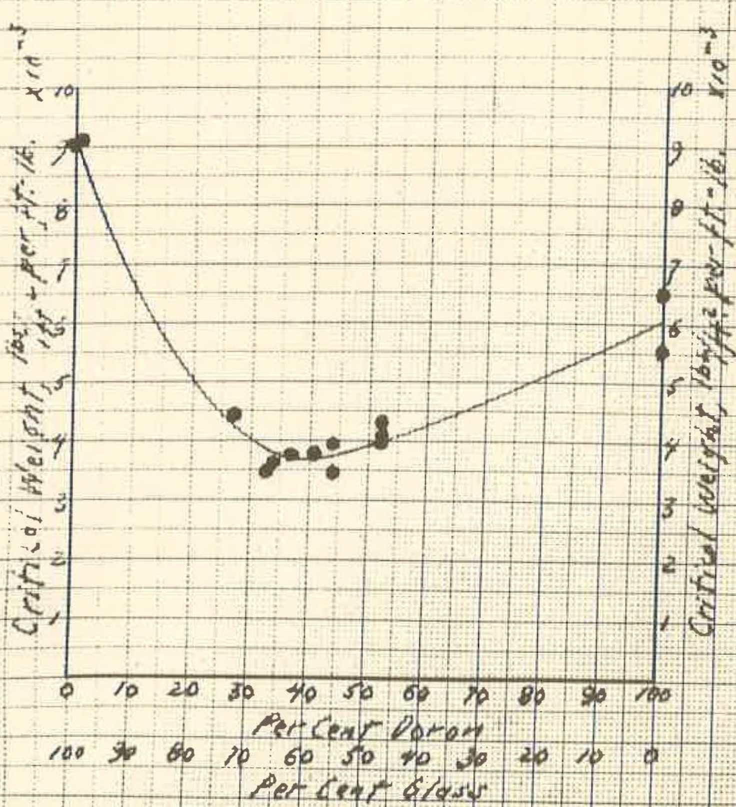
Fig. 4

Ballistic Resistance Diagram
Glass - Doron
to Carbine and M2 (Ball)

% Doron	Critical Weight	% Doron	Critical weight
0	9.08	44.0	3.46
0	9.07	44.0	3.72
26.7	4.46	52.8	4.06
32.7	3.48	52.8	4.30
33.8	3.59	52.8	3.94
36.8	3.76	100	5.54
40.5	3.76	100	6.54



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